

AIRCRAFT NAVIGATION AID METHOD AND DEVICE

The invention relates to an aircraft navigation aid method.

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The field of the invention is that of air navigation and safety aid and relates more particularly to ground avoidance maneuvers.

- 10 Onboard devices for performing vertical avoidance maneuvers are already known.

Such a device described in patent EP 0 565 399 comprises in particular a mass memory for storing
15 topographical data representing a substantial portion of the surface of the earth, a fast-access working memory into which is transferred the topographical data corresponding to the flight area of the aircraft and means of predicting the path of the aircraft, based on
20 status indications relating to the longitude, latitude, altitude, speed and acceleration of the aircraft. The planned path is compared to the topographical data in the fast-access memory; in the event of a potential collision with the ground, an alarm is triggered and a
25 vertical avoidance maneuver is suggested to the pilot.

In some cases, particularly on approaches or take-offs in mountainous areas, the aircraft nears the ground without that fact constituting a threat or an
30 abnormality. The collision-avoidance device is then set to a specific mode designed to reduce the rate of false alarms; however, when a threat is detected, the vertical avoidance maneuver is often no longer possible.

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Another device described in patent EP 0 802 469, refining the above device, further suggests to the pilot a lateral avoidance maneuver when the vertical avoidance maneuver is no longer possible. A first and

then a second alarm are triggered when the aircraft crosses respective thresholds of 20 then 5 seconds before the point of no return, in other words before the ultimate point from which an avoidance maneuver must absolutely have been started.

These predefined thresholds are not always suited to the area in which the aircraft is flying, and this device does not provide for continuous monitoring of how the danger changes; it does not truly quantify the danger, in other words continually determine the time remaining to undertake a lateral avoidance maneuver to the right or to the left before the point of no return.

An important object of the invention is therefore to determine continually the time remaining to undertake an avoidance maneuver before the point of no return.

To achieve these aims, the invention proposes an aircraft navigation aid method, mainly characterized in that it comprises the following steps consisting in:

- a) defining an area to be sensed to the right and to the left of a first hypothetical path of the aircraft, designated the feeler line support path,
- b) sensing, for each of the two areas to be sensed to the right and to the left, a corresponding predefined underlying relief, in order to identify dangerous sub-zones to the right and/or to the left,
- c) computing, for each of the dangerous sub-zones to the right and/or to the left, a time ΔT remaining to begin an avoidance maneuver before a point of no return, and determining for the dangerous sub-zones to the right a minimum ΔT denoted ΔT right and/or for the dangerous sub-zones to the left a minimum ΔT denoted ΔT left,
- d) establishing a navigation aid from ΔT right and/or ΔT left.

The method according to the invention thus comprises a

number of steps mainly consisting in sensing along a feeler line support path of the aircraft and to each side of the latter, the relief underlying an area marked out by grids, for example, identifying the grids
5 presenting a potential danger and, for these grids, the time remaining before undertaking an avoidance maneuver.

According to a feature of the invention, the feeler
10 line support path is determined during a time T broken down into a pilot reaction time T_{reac} , a time T_{pull} for placing the aircraft on a horizontal path and the time T_{roll} for placing the aircraft in a roll.

15 According to another feature of the invention, the dangerous sub-zones of step b) are identified according to a second hypothetical path of the aircraft such that:

if the aircraft is ascending, the ascent is stopped
20 immediately,
in other cases, the path is continued unchanged.

The purpose of this second hypothetical path is to increase the safety margin of the method.
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The time ΔT of step c) is advantageously computed according to a hypothetical flight time toward a dangerous sub-zone, calculated according to a time T_{pull} to place the aircraft on a horizontal path and a time
30 T_{roll} to place the aircraft in a roll:
in a horizontal plane when the aircraft is ascending or is flying level,
in a horizontal plane and in a vertical plane when the aircraft is descending.

35 According to another feature of the invention, step d) comprises a step for comparing ΔT right and/or ΔT left with one or more predefined times and, where appropriate, a step consisting in determining the time

remaining for the safest side (best lateral) from the maximum between ΔT right and/or ΔT left and the time remaining for the least safe side (worst lateral) from the minimum between ΔT right and/or ΔT left.

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Another object of the invention is to produce an aircraft navigation aid device, comprising a mass memory designed to store a terrain database, a program memory comprising an application program of the method as described, a central processing unit designed to run the program and an input/output interface.

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Other features and advantages of the invention will become apparent on reading the detailed description that follows, given by way of non-limiting example and with reference to the appended drawings in which:

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figure 1 diagrammatically represents right and left rings C_r and C_l respectively in an unbalanced case,

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figures 2a, 2b diagrammatically represent, in a horizontal plane, examples of areas to be sensed in the case of an initial straight line (2a) and turning (2b) path and figure 2c diagrammatically represents, in a vertical plane, an example of path supporting these areas to be sensed,

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figure 3 diagrammatically represents the grid of the relief underlying a ring C_r ,

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figures 4a and 4b respectively and diagrammatically represent, in a vertical then horizontal plane, path sections during defined times, and figure 4c diagrammatically illustrates, in a horizontal plane, the time remaining for the best lateral and the worst lateral,

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figure 5 diagrammatically represents an example of presentation of navigation aid information,

figure 6 diagrammatically represents an example of a device for implementing the navigation aid method as described.

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The invention relates to an aircraft navigation aid; in the description that follows, an airplane will be taken as a typical aircraft. It will also be assumed that the navigation aid relates to the pilot; it may more generally relate to a piloting system in particular in the case of an automatic pilot.

The method according to the invention comprises a number of steps mainly consisting in sensing, along a hypothetical path of the aircraft and to each side of the latter, the relief underlying a strip of terrain identified by grids, identifying the grids presenting a potential danger and, for these grids, the time remaining before undertaking an avoidance maneuver.

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The first step consists in defining an area to be sensed to the right and to the left of a hypothetical path of the airplane which is designated in the description below as a feeler line support path and which is determined for a time T as will be seen later.

The term feeler line or area to be sensed is the shape defined by a succession of rings along this feeler line support path.

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Two rings, respectively right Cr and left Cl, are represented in figure 1. The diameter D of each ring is of the form:

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$$D = d + HSM + HPU$$

d being the diameter of the avoidance maneuver circle, HSM being a horizontal safety margin, HPU being a horizontal position uncertainty.

For an Airbus 340, for example, HSM = 220 m and HPU = 100 m.

5 As can be seen in figure 1, the right and left rings Cr and Cl respectively overlap the feeler line support path; they also overlap each other when they are not offset as shown in this figure 1. Only the right and left avoidance circles are tangential to the path and
10 tangential to each other when the rings are not offset.

From the current position of the aircraft, the right rings succeed each other continuously, remaining tangential to the feeler line support path; the same
15 applies for the left rings Cl. Figure 2a shows three left rings Cl succeeding each other at times t, t' and t''. These successions of rings occurring between the time t0 corresponding to the current position of the airplane and a time T defined later thus define an area
20 to be sensed to the right and to the left represented in a horizontal plane in figures 2a and 2b according to whether the initial path of the airplane is straight or turning. These areas to be sensed are in the form of strips.

25 The feeler line support path of the airplane is determined during a time $T = T_{\text{reac}} + T_{\text{pull}} + T_{\text{roll}}$, the path sections respectively corresponding to these times T_{reac} , T_{pull} and T_{roll} as represented in a vertical plane
30 in figure 2c. The terms are defined as follows:

- T_{reac} is the reaction time of the pilot (or of the piloting unit) before starting the avoidance maneuver, in other words the time during which the airplane continues on its path without changing
35 parameters (speed unchanged as an absolute value, turn radius unchanged if the airplane is turning, gradient unchanged if the airplane is descending). This time T_{reac} is defined by default; as an example $T_{\text{reac}} = 25 \text{ sec}$ could apply when the aircraft is

descending and $T_{\text{reac}} = 0$ sec could apply when the airplane is ascending,

- T_{pull} is the time needed for the airplane to perform a pull-out in the vertical plane, in other words to return to a horizontal path when the airplane is initially descending or ascending; when the situation demands a lateral avoidance maneuver, the pilot will first of all make himself safe with respect to the relief in the vertical plane by stopping the vertical change as early as possible; conventionally, $T_{\text{pull}} = |\gamma_0| \times V / \text{fcv}$, γ_0 being the gradient of the airplane, V its current speed and fcv its vertical loading factor.
- T_{roll} is the time to place the airplane in a roll in order to perform an avoidance turn (or circle); placing in a roll consists in changing the roll from its initial value to a final value equal, for example, to $\pm 33^\circ$ (the sign depending on the direction of turn toward the right or toward the left) taking into account a roll rate equal, for example, to $7^\circ/\text{sec}$ for an A340 type airplane. T_{roll} can be equal to 0 when the placing in a roll coincides with the current turn of the airplane. Although placing in a roll is translated by a placing in a turn, it is artificially assumed that the feeler line support path during this time T_{roll} is the same as the current path and is therefore straight if the current path of the airplane was straight; this represents an additional safety margin.

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As is represented in the horizontal plane in figure 2a, when the current path of the airplane is straight, in other words presenting a roll angle less than 1° for example, the time $T_{\text{reac}} + T_{\text{pull}} + T_{\text{roll}}$ for each of the rings is the same to the right and to the left of the feeler line support path and the areas to be sensed to the right and to the left are the same.

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When the current path of the airplane is a turn, as is

represented in the horizontal plane in figure 2b in the case of a current turn to the right, the areas to be sensed to the right and to the left differ not only for obvious reasons of geometry but also because the time $T_{\text{reac}} + T_{\text{pull}} + T_{\text{roll}}$ differs between a ring to the right and a ring to the left. In practice, the times T_{reac} and T_{pull} are the same; however, when the placing in a roll consists in continuing or accentuating the roll of the current turn, the time to place in a roll is less than the contrary case for which it is first of all necessary to reestablish a straight line path before placing in the required roll opposite to the roll of the current turn. There is then a distinction between a time to place in a roll to the right T_{rollr} and a time to place in a roll to the left T_{rolll} . In the case of a current turn to the right as represented in figure 2b, $T_{\text{rollr}} < T_{\text{rolll}}$.

Furthermore, it is preferably planned that the speed V_{turn} at which the maneuver is performed during T_{rolll} or T_{rollr} is equal to the speed of the airplane in its current position uprated by $x\%$ ($x\% = 10\%$, for example). This speed variation occurs during $T_{\text{reac}} + T_{\text{pull}}$. The feeler line support path then comprises two parts: the point C is the center of the circle representing the feeler line support path during $T_{\text{reac}} + T_{\text{pull}}$ and C' is the center of the circle representing the feeler line support path during T_{rollr} or T_{rolll} , the turn being performed at the speed V_{turn} . Although the path during $T_{\text{reac}} + T_{\text{pull}}$ is not exactly a circle, since the speed varies, it is sufficiently close to a circle for this approximation to be made.

Overall, the feeler line support path is, in the horizontal plane, the continuation of the current straight line or turn (to within this approximation), during $T_{\text{reac}} + T_{\text{pull}} + T_{\text{roll}}$. In the vertical plane, the vertical change is stopped to return to a horizontal path, during $T_{\text{reac}} + T_{\text{pull}}$ when the airplane is descending

and during T_{pull} when the airplane is ascending (which corresponds to the worst case ascending).

5 The airplane moreover has a terrain database comprising topographical data representative of the relief of the earth and in particular of that over which the airplane is or will be flying. This digitized topographical data is conventionally identified according to a grid reference.

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In a second step, this topographical data is used to determine the potential dangers of the relief underlying the areas to be sensed to the right and to the left.

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To do this, the areas to be sensed are parameterized so that the digitized relief grids corresponding to these areas, and all the grids in which at least one peak belongs to an area to be sensed are sensed, can be
20 extracted from the terrain database. Figure 3 represents, in the horizontal plane, the grids corresponding to a right ring C_r and the grids of preceding rings.

25 For each grid tested, the potential danger is determined by comparing $Z_{critical}$ to $Z_{relief} + VSM$, Z_{relief} being the altitude of the grid concerned, VSM being a vertical safety margin varying, for example, with the distance between the airplane and the
30 nearest airport, this safety margin typically being 100 m,

and $Z_{critical}$ being a hypothetical altitude defined as being the altitude that the airplane would have when flying over the grid in the case where:

35 if it is ascending, the ascent would be stopped immediately,
if it is descending, the descent would be continued unchanged,
if it is flying level, the level would be continued

unchanged.

Thus, the lateral grids presenting a danger, in other words grids for which $Z_{critical} < Z_{relief} + VSM$, are identified. These dangerous grids can be highlighted, in particular displayed on a screen for the attention of the pilot.

For each of the dangerous grids, a third step is used to calculate the time ΔT remaining before the start of the avoidance maneuver, in other words the maximum reaction time T_{reac} that the pilot has before performing a pull-out in the vertical plane.

This remaining time ΔT is calculated by reconstructing a hypothetical flight time toward the point considered dangerous, in other words the obstacle of the dangerous grid. This flight time is calculated in the vertical plane as illustrated in figure 4a; it is also calculated in the horizontal plane as illustrated in figure 4b, distinguishing the case of a straight-line flight from that of a turning flight.

The time ΔT is equal to the maximum of the corresponding times in the horizontal plane and in the vertical plane for the case where the airplane is descending, and to the horizontal flight time only for the case where the airplane is ascending or flying level.

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	$\Delta T_{h \text{ str}}$	ascending, straight
	$\Delta T_{h \text{ turn}}$	ascending, turning
$\Delta T =$	$\max(\Delta T_{h \text{ str}}, \Delta T_v)$	descending, straight
	$\max(\Delta T_{h \text{ turn}}, \Delta T_v)$	descending, turning,

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$\Delta T_{h \text{ str}}$ defining the time remaining in the horizontal plane when the current path of the airplane is straight,

$\Delta T_{h \text{ turn}}$ defining the time remaining in the horizontal

plane when the current path of the airplane is turning,
 ΔT_v defining the time remaining in the vertical plane
 regardless of the current path of the airplane. It is
 more specifically the time remaining for the pilot
 5 before performing a pull-out to obtain a horizontal
 path in order, without any lateral avoidance maneuver,
 to avoid the obstacle identified in the grid considered
 dangerous, taking into account a vertical safety margin
 VSM: in practice, normally $\max(\Delta T_h, \Delta T_v) = \Delta T_h$ applies,
 10 unless, as is represented in figure 4a, ΔT_v enables the
 pilot to fly over the obstacle.

We have:

$$\Delta T_{hstr} = \frac{D - R_{\phi f} - HSM - HPU}{V} - T_{pull} - T_{roll}$$

$$\Delta T_{hturn} = \frac{2R_{\phi i} * \arcsin\left(\frac{D - R_{\phi f} - HSM - HPU}{2R_{\phi i}}\right)}{V} - T_{pull} - T_{roll}$$

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with, as indicated in figure 4b in the case of a
 straight line path, D being the distance between the
 current position of the airplane and the obstacle, $R_{\phi f}$
 20 being the radius of the avoidance circle, $R_{\phi i}$ being the
 radius of the current turn, HSM being a horizontal
 safety margin and HPU being uncertainty concerning the
 current position and V being the current speed of the
 airplane; $\Delta T_{hturn} = T_{reac}$ is assumed if \arcsin is
 25 undefined.

$$\text{And } \Delta T_v = \frac{z - (z_{terrain} + VSM) - \frac{V^2}{fcv}(1 - \cos \gamma_0)}{-V \sin \gamma_0}$$

with, as indicated in figure 4a, z being the current altitude of the airplane, z_{terrain} being the altitude of the obstacle, VSM being a vertical safety margin, V being the current speed of the airplane, fcv being the vertical loading factor of the airplane and γ_0 being its gradient.

For each of the left and right sides, the minimum of these ΔT values is then identified over all of the dangerous grids, and it is designated ΔT_{right} and ΔT_{left} . These ΔT_{right} and ΔT_{left} values correspond to the nearest dangerous right and left grids, as illustrated in figure 4c; here, too, these grids can be highlighted, for the attention of the pilot.

It may be that one of these ΔT_{right} or ΔT_{left} values does not exist when, for example, no dangerous grid has been identified on one side.

As illustrated in the horizontal plane in figure 4c, the time remaining for the most critical side, in other words the least safe side (the right side in the figure), called the worst lateral (WL), is the one corresponding to the minimum between ΔT_{right} and ΔT_{left} and the time remaining for the safest side (left side in the figure), called the best lateral (BL), is that corresponding to the maximum reaction time T_{reac} which is equal to the maximum between ΔT_{right} and ΔT_{left} .

The fourth step corresponding to an alert management step then begins.

When BL and WL exist, they are compared to predefined times, such as, for example, a time T_{caution} and a time T_{warning} . As an example, $T_{\text{caution}} = 20 \text{ sec}$ and $T_{\text{warning}} = 8 \text{ sec}$.

Four classes can then be distinguished for each side:
"Infinite" when BL (or WL) is greater than T_{caution} ,

- "Danger" when BL (or WL) is less than or equal to T_{caution} and greater than T_{warning} ,
"Critical" when BL (or WL) is less than or equal to T_{warning} and greater than 0 seconds,
5 "Fatal" or "impossible" when BL (or WL) is less than or equal to 0 seconds.

The same classes can also be defined for a vertical time remaining T_v ; the aforementioned patents should be
10 referred to for information on how to compute T_v .

By combining these four classes for each of the T_v , BL and WL, subclasses are obtained, to which are linked notices and/or advice and/or orders, as indicated in
15 the table below, in which the sub-classes are identified by numbers ranging from 1 to 40.

	Vertical	Best lateral ("BL")	Worst lateral ("WL")	Notice	Advice	Command
1	Infinite	Infinite	Infinite	Cautious WL	Continue on path	
2	Infinite	Infinite	Danger	Warning WL	Continue on path (avoid turn WL)	
3	Infinite	Infinite	Critical	Avoid WL	Continue on path (avoid turn WL)	
4	Infinite	Infinite	Impossible	Cautious Lateral	Continue on path (avoid turn WL)	
5	Infinite	Danger	Danger	Warning WL/Cautious BL	Continue on path (avoid turn lateral)	
6	Infinite	Danger	Critical	Avoid WL/Cautious BL	Continue on path (avoid turn lateral)	
7	Infinite	Danger	Impossible	Warning Lateral	Continue on path (avoid turn lateral)	
8	Infinite	Critical	Critical	Warning Lateral	Continue on path (avoid turn lateral)	
9	Infinite	Critical	Impossible	Avoid WL/Warning BL	Continue on path (avoid turn lateral)	
10	Infinite	Impossible	Impossible	Avoid Lateral	Continue on path (avoid turn lateral)	
11	Danger	Infinite	Infinite	Cautious Vertical	Climb (or turn BL)	Dangerous terrain
12	Danger	Infinite	Danger	Cautious Vertical and WL	Climb (or turn BL)	Dangerous terrain
13	Danger	Infinite	Critical	Warning WL/Cautious Vertical	Climb (or turn BL)	Dangerous terrain
14	Danger	Infinite	Impossible	Avoid WL/Cautious Vertical	Climb (or turn BL)	Dangerous terrain
15	Danger	Danger	Danger	Cautious Vertical and Lateral	Climb (or turn quickly BL)	Dangerous terrain
16	Danger	Danger	Critical	Warning WL/Cautious Vertical and BL	Climb (or turn quickly BL)	Dangerous terrain
17	Danger	Danger	Impossible	Avoid WL/Cautious Vertical and BL	Climb (or turn quickly BL)	Dangerous terrain
18	Danger	Critical	Critical	Warning Lateral/Cautious Vertical	Climb (or turn immediately BL)	Dangerous terrain
19	Danger	Critical	Impossible	Avoid WL/Warning BL/Cautious Vertical	Climb (or turn immediately BL)	Dangerous terrain
20	Danger	Impossible	Impossible	Avoid Lateral/Cautious Vertical	Climb (avoid turn lateral)	Dangerous terrain
21	Critical	Infinite	Infinite	Warning Vertical	Climb immediately (or turn BL)	Ascend
22	Critical	Infinite	Danger	Warning Vertical/Cautious WL	Climb immediately (or turn BL)	Ascend
23	Critical	Infinite	Critical	Warning Vertical and WL	Climb immediately (or turn BL)	Ascend
24	Critical	Infinite	Impossible	Avoid WL/Warning Vertical	Climb immediately (or turn BL)	Ascend
25	Critical	Danger	Danger	Warning Vertical/Cautious Lateral	Climb immediately (or turn rapidly BL)	Ascend
26	Critical	Danger	Critical	Warning Vertical and WL/Cautious BL	Climb immediately (or turn rapidly BL)	Ascend
27	Critical	Danger	Impossible	Avoid WL/Warning Vertical	Climb immediately (or turn rapidly BL)	Ascend
28	Critical	Critical	Critical	Warning Vertical and Lateral	Climb immediately (or turn rapidly BL)	Ascend
29	Critical	Critical	Impossible	Avoid WL/Warning Vertical and BL	Climb immediately (or turn immediately BL)	Ascend
30	Critical	Impossible	Impossible	Avoid lateral/Warning Vertical	Climb immediately (or turn immediately BL)	Ascend
31	Impossible	Infinite	Infinite	Avoid Vertical	Turn BL	Turn BL
32	Impossible	Infinite	Danger	Avoid Vertical/Cautious WL	Turn BL	Turn BL
33	Impossible	Infinite	Critical	Avoid Vertical/Warning WL	Turn BL	Turn BL
34	Impossible	Infinite	Impossible	Avoid Vertical and WL	Turn BL	Turn BL
35	Impossible	Danger	Danger	Avoid Vertical/Cautious Lateral	Turn rapidly BL	Turn BL now
36	Impossible	Danger	Critical	Avoid Vertical/Warning WL/Cautious BL	Turn rapidly BL	Turn BL now
37	Impossible	Danger	Impossible	Avoid Vertical and WL/Cautious BL	Turn rapidly BL	Turn BL now
38	Impossible	Critical	Critical	Avoid Vertical/Cautious Lateral	Turn immediately BL	Turn BL immediately
39	Impossible	Critical	Impossible	Avoid Vertical and WL/Warning BL	Turn immediately BL	Turn BL immediately
40	Impossible	Impossible	Impossible	Collision with terrain	Collision with terrain	Collision with terrain

Information obtained from this table can be displayed, for example, in the form of colored areas, the fill pattern of which is proportional to the respective values of V_t , ΔT_{right} and ΔT_{left} . An example of how this information could be presented is illustrated in figure 5.

There now follows a description of the lateral avoidance maneuver proper, occurring at the end of a time less than or equal to $T_{\text{reac maximum}} + T_{\text{pull}} + T_{\text{roll}}$.

It concerns a circular maneuver accomplished in the horizontal plane tangential to the preceding path section, in the direction corresponding to that recommended after the preceding step and for which the radius R conventionally takes the form:

$$R = V_{\text{turn}}^2 / (g \cdot \tan \varphi)$$

V_{turn} being the turning speed, g being the gravitational acceleration ($g = 9.81 \text{ m/s}^2$), φ being the roll angle.

The speed V_{turn} at which the turn is made is equal to the speed of the airplane in its current position, uprated by 10%, for example, while being limited to a maximum V_{max} dependent on regulations and on the configuration of the airplane. For example, for an A340 type airplane, V_{max} varies according to its configuration (landing gear down and/or flaps deployed) between 180 knots and 205 knots (1 knot \cong 1852 m/h).

The method according to the invention is implemented in a navigation aid device preferably on board the airplane; the device may, if necessary, be part of an aircraft radio control system.

As is represented in figure 6, the navigation aid device 1 conventionally comprises at least a mass memory 2 designed to store a terrain database, a

program memory 3 comprising an application program of the method described, a central processing unit 4 designed to run the program and an input-output interface 5.

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The computations are overall performed, for example, at 100-millisecond intervals.